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Equipment for Nonlinear Photonics Research

Zhigang Chen
SAN FRANCISCO STATE UNIVERSITY

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Final Report

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Zhigang Chen

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14. ABSTRACT

In the past year, we successfully demonstrated several phenomena related to light localization, light beam manipulation, and light signal routing in free-space as well as in optically-induced photonic bandgap structures, including elimination of transverse instability in stripe solitons by one-dimensional lattices, linear and nonlinear control of optical beams in optical periodic structures. In particular, we predicted and demonstrated a new class of nonconventional edge states in optically induced honey-comb lattices - an optical analog of graphene, which has been published in Nature Material and Physics Review Letters. Our work was reported in a number of news media as well as featured in PRL cover. We are happy to report that we have made significant progress in this funded project with already many scientific research papers published in top-rated refereed journals (See attached list of publications that acknowledged the support from AFOSR). In addition, several students have actively involved in this project, and close collaboration has been maintained with other principal investigators supported by AFOSR.

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Final Performance Report (March 2014)

Zhigang Chen
San Francisco State University
zhigang@sfsu.edu

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Abstract:

The primary objective of the project is to develop research programs at the frontier of nonlinear optics/photonics that could lead to fundamental understandings in scientific knowledge as well as possible applications of direct interest to AFOSR. Specifically, this equipment proposal was awarded for purchasing equipment that would enhance the progress of a current AFOSR grant (*FA9550-12-1-0111*) managed by Dr. Nachman.

In this project, funds were requested to develop innovative techniques to optically induce 2D and 3D photonic lattices with coupling or modulation properties different from those of traditional square lattices. Fundamental phenomena in those specially-designed photonic structures along with their possible applications in light control and image transmission have been explored. Examples include nonconventional edge states and topological surface states in 2D honey-comb (graphene-like) photonic lattices, and light localization and transport in disordered lattices. During the project year, the P.I. and his team has already made significant progress in the proposed research, with several important papers published in leading journals such as *Nature Materials*, *Physics Review Letters*, and *Optics Letters*.

The equipment funds ($145k) were used mainly to purchase a new laser source and beam-view analyzing CCD system with a high-quality camera. The equipment acquired enhanced significantly the experimental capacity in P.I. optics research lab, permitting a few experimental setups running simultaneously. In particular, a new solid-state laser was purchased to replace the old Ar+ laser that was closing to the end of its lifetime. Acquisition of these equipments not only will benefit the current project, but also enhance the nonlinear optics and photonics research programs at San Francisco State University, one of the HBCU/MI institutes among the top ten universities for campus diversity.

Summary of Major Efforts and Accomplishments:

In the past year, we successfully demonstrated several phenomena related to light localization, light beam manipulation, and light signal routing in free-space as well as in optically-induced photonic bandgap structures, including elimination of transverse instability in stripe solitons by one-dimensional lattices, linear and nonlinear control of optical beams in optical periodic structures. In particular, we predicted and demonstrated a new class of nonconventional edge states in optically induced honey-comb lattices - an optical analog of graphene, which has been published in *Nature Material* and *Physics Review Letters*. Our work was reported in a number of news media as well as featured in PRL cover. We are happy to report that we have made significant progress in this funded project with already many scientific research papers published in top-rated refereed journals (See attached list of publications that acknowledged the support from AFOSR). In addition, several students have actively involved in this project, and close collaboration has been maintained with other principal investigators supported by AFOSR. Below, we provide a brief summary of our major accomplishments.

1. *Observation of unconventional edge states in'photonic graphene'*

Graphene, a two-dimensional honeycomb lattice of carbon atoms, has been attracting much interest in recent years. Electrons therein behave as massless relativistic particles, giving rise to strikingly unconventional phenomena. Graphene edge states are essential for understanding the electronic properties of this material. However, the coarse or impure nature of the graphene edges hampers the ability to directly probe the edge states. We use the optical equivalent of graphene—a photonic honeycomb lattice—to study the edge states and their properties, and find a new type of edge state: one residing on the bearded edge that has never been predicted or observed. In addition, we experimentally demonstrate a topological transition of classical light in ''photonic graphene'': an array of waveguides arranged in the honeycomb geometry. As the system is uniaxially strained (compressed), the two unique Dirac points (present in the spectrum of conventional graphene) merge and annihilate each other, and a band gap forms. As a result, edge states are created on the zigzag edge and destroyed on the bearded edge.
This part of the work has been published in *Nature Materials and Physical Review Letters.*

2. *Linear and nonlinear nonparaxial self-accelerating beams*

We studied linear and nonlinear self-accelerating beams propagating along circular trajectories beyond the paraxial approximation. Such nonparaxial accelerating beams are exact solutions of the Helmholtz equation, preserving their shapes during propagation even under nonlinearity. We generate experimentally and observe directly these large-angle bending beams in colloidal suspensions of polystyrene nano-particles. In addition, we demonstrated both theoretically and experimentally nonparaxial Mathieu and Weber accelerating beams, generalizing the concept of previously found accelerating beams. We showed that such beams bend into large angles along circular, elliptical, or parabolic trajectories but still retain nondiffracting and self-healing capabilities. Not only do

generalized nonparaxial accelerating beams open up many possibilities of beam engineering for applications, but the fundamental concept developed here can be applied to other linear wave systems in nature, ranging from electromagnetic and elastic waves to matter waves.

This part of the work has merited a few papers published in *Optics Letters and Physical Review Letters.*

3. Elimination of transverse instability in stripe solitons by one-dimensional lattices

In collaboration with AFOSR contractor Dr. J. Yang, we demonstrate theoretically and experimentally that the transverse instability of coherent soliton stripes can be greatly suppressed or totally eliminated when the soliton stripes propagate in a one-dimensional photonic lattice under self-defocusing nonlinearity. Both schemes and demonstrations were published in *Optics Letters.*

4. Observation of self-accelerating Bessel-like optical beams along arbitrary trajectories

In collaboration with AFOSR contractor Dr. Christodoulides, we proposed and experimentally demonstrated self-accelerating Bessel-like optical beams propagating along arbitrary trajectories in free space. With computer generated holography, such beams are designed to follow different controllable trajectories while their main lobe transverse profiles remain nearly invariant and symmetric. Examples include parabolic, snake-like, hyperbolic, hyperbolic secant, and even three-dimensional spiraling trajectories. The self-healing property of such beams is also demonstrated. This new class of optical beams can be considered as a hybrid between accelerating and non-accelerating nondiffracting beams that may find a variety of applications. This part of work was published in *Optics Letters.*

Publications Acknowledged AFOSR Support in 2013-14:

Referred Journal Actricles:

- J. Zhao, P. Zhang, D. Deng, J. Liu, Y. Gao, I. D. Chremmos, N. K. Efremidis, D. N. Christodoulides, and Z. Chen, "Observation of self-accelerating Bessel-like optical beams along arbitrary trajectories," Opt. Lett. **38**, 498-500 (2013).
- Y. Hu, M. Li, D. Bongiovanni, M. Clerici, J. Yao, Z. Chen, J. Azaña, and R. Morandotti, "Spectrum to distance mapping via nonlinear Airy pulses," Opt. Lett. **38**, 380-382 (2013).
- Z. Zhang, P. Zhang, M. Mills, Z. Chen, D. N. Christodoulides, and J. Liu, "Trapping aerosols with optical bottle arrays generated through a superposition of multiple Airy beams," Chin. Opt. Lett. **11**, 033502 (2013).
- Y. Liang, Z. Ye, D. Song, C. Lou, X. Zhang, J. Xu, and Z. Chen, "Generation of linear and nonlinear propagation of three-Airy beams," Opt. Express **21**, 1615-1622 (2013).
- Z. Zhang, J.J. Liu, P. Zhang, P.G. Ni, J, Prakash, Y. Hu, D.S. Jiang, D.N. Christodoulides, and Z. Chen, "Generation of autofocusing beams with multi-Airy beams", ACTA PHYSICA SINICA, **62**, 034209 (2013).
- M. C. Rechtsman, Y. Plotnik, J. M. Zeuner, D. Song, Z. Chen, A. Szameit and M. Segev, "Topological Creation and Destruction of Edge States in Photonic Graphene", Phys. Rev. Lett., **111**, 103901 (2013).
- R. Driben, Y. Hu, Z. Chen, B. A. Malomed, and R. Morandotti, "Inversion and tight focusing of Airy pulses under the action of third-order dispersion," Opt. Lett. **38**, 2499-2501 (2013).
- Y. Hu, D. Bongiovanni, Z. Chen and R. Morandotti, "Periodic self-accelerating beams by combined phase and amplitude modulation in the Fourier space," Opt. Lett. **38**, 3387-3389 (2013).
- S. Fardad, M. S. Mills, P. Zhang. W. Man, Z. Chen, and D.N. Christodoulides, "Interactions between self-channeled optical beams in soft-matter systems with artificial nonlinearities", Opt. Lett. **38**, 3585 (2013).
- D. Deng, Y. Gao, J. Zhao, P. Zhang, and Z. Chen, "Three-dimensional nonparaxial beams in parabolic rotational coordinates," Opt. Lett. **38**, 3934-3936 (2013).
- J. Zhao, P. Zhang, D. Deng, C. Lou, D. Song, J. Liu, and Z. Chen, "Self-accelerating and self-breathing Bessel-like beams along arbitrary trajectories," Chin. Opt. Lett. **11**, 110701 (2013).
- Y. Hu, D. Bongiovanni, Z. Chen and R. Morandotti, "Multi-path multi-component self-accelerating beams through spectrum-engineered position mapping", Phys. Rev. A, **88**, 043809 (2013).
- W. Man, S. Fardad, Z. Zhang, J. Prakash, M. Lau*,, P. Zhang, M. Heinrich, D. N. Christodoulides, and Z. Chen, "Engineered optical nonlinearities and enhanced light transmission in soft-matter systems with tunable polarizabilities", Phys. Rev. Lett., **111**, 218302 (2013).
- Z. Zhang, Z. Ye, D. Song, P. Zhang, Z. Chen, "Repositioning and steering laser beam power via coherent combination of multiple Airy beams", APPLIED OPTICS / Vol. **52**, 8512 (2013).
- Y. Plotnik, M. C. Rechtsman, D. Song, M. Heinrich, J. M. Zeuner, S. Nolte, N. Malkova, J. Xu, A. Szameit, Z. Chen, and M. Segev, "Observation of unconventional edges states in photonic graphene", Nature Material,**13**, 57 (2014) (published online: 10 November 2013 | doi:10.1038/nmat3783)
- X. Qi, K.G. Makris, R. El-Ganainy, P. Zhang, J. Bai, D. N. Christodoulides, and Z. Chen, "Observation of accelerating Wannier–Stark beams in optically induced photonic lattices," Opt. Lett. **39**, 1065-1068 (2014)